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Electro Scientific Industries
7524 S. W. MACADAM AVE. • PORTLAND 19, OREGON

BRIDGES
AND
ACCESSORIES

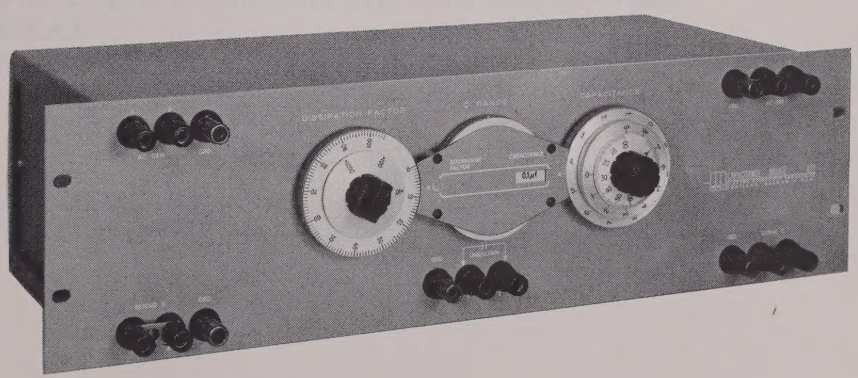
APRIL 1963

MODEL

277

Instruction Manual

CAPACITANCE BRIDGE



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SECTION I

DESCRIPTION AND SPECIFICATIONS

1.1 DESCRIPTION

The ESI MODEL 277 CAPACITANCE BRIDGE is designed for rapid and accurate measurement of two or three terminal capacitors. The value of the capacitance being measured is presented on in-line reading dials. The correct multiplier and unit are indicated on the range dial and logically presented in line with the capacitance reading dials.

The internal shielding of the bridge excludes stray capacity in parallel with the unknown, eliminating the need of corrections for zero capacitance. The bridge maybe periodically checked and adjusted to agree with a NBS certified standard to correct for the long term drift.

1.2 SPECIFICATIONS

CAPACITANCE READINGS

NUMBER OF RANGES - Seven.
DIAL RESOLUTION - 12,005 divisions full scale on any range.
HIGHEST RANGE - 0 to 120μf.
LOWEST RANGE - 0 to 120pf; 1 dial division represents 0.01pf.
ACCURACY* - On the five intermediate ranges: ±(0.1% + 1 dial division).
On highest range and lowest range: ±(0.2% + 1 dial division).

DISSIPATION FACTOR READINGS

NUMBER OF RANGES - Three.
DIAL RESOLUTION - 105 divisions full scale on any range.
HIGHEST RANGE - 0 to 1.05 x frequency in kilocycles.
LOWEST RANGE - 0 to 0.0105 x frequency in kilocycles; at 1 kc, 1 dial division represents a D of 0.0001.
ACCURACY* - ±(2% + 0.0005).

*NOTE: Accuracy ratings apply at a frequency of 1 kc and a temperature of 25°C. Slightly larger errors may be encountered at frequency or temperature extremes. Capacitance accuracy specifications apply when the bridge has been recently standardized against a reference standard capacitor. The long-term drift in calibration will not exceed 0.1% per year, and any such drift can be corrected by a single adjustment to restandardize the bridge against any certified reference standard capacitor.

1.3 ACCESSORY REQUIREMENTS

Although the MODEL 277 CAPACITANCE BRIDGE is a high accuracy high resolution bridge, its performance can be severely impaired by using an inadequate generator or detector with it. The following two paragraphs are intended to point out the principal requirements that the generator and detector must meet in order that the full capabilities of the bridge be realized. The ESI ac generator-detectors meet these requirements and are recommended for use with MODEL 277 CAPACITANCE BRIDGE.

1.3.1 GENERATOR REQUIREMENTS

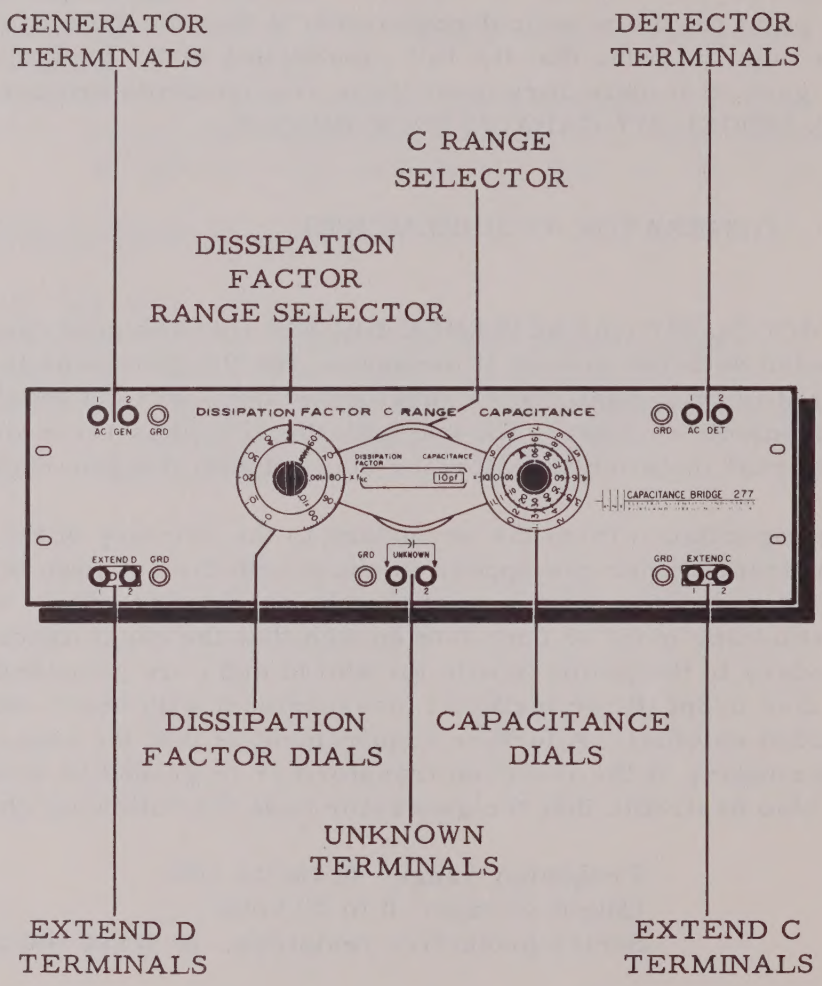
The MODEL 277 CAPACITANCE BRIDGE was designed for use with a grounded detector making it necessary for the generator to be well isolated from ground. Since most generators will not meet the isolation requirements necessary for use with the 277, it is recommended that an external isolation transformer be used with the generator.

Since capacitance from the secondary to the primary of the generator output transformer can appear in shunt with the unknown terminals of the bridge, it is necessary that they be shielded from one another. The shielding must be complete enough that the capacitance from the secondary to the primary with the shield and core grounded should be less than 0.2pf (three terminal measurement with leads enclosed in grounded shields). A further requirement is that the capacitance from the secondary of the isolation transformer to ground be less than 30pf. It is also desirable that the generator have the following characteristics:

Frequency range: 0.1kc to 10kc
Output voltage: 0 to 20 volts
Series protective resistors: At least 100 ohms

1.3.2 DETECTOR REQUIREMENTS

The detector and the input leads to the detector must be well shielded to prevent electrostatic pickup, especially from the generator. It is also desirable that the detector be tuned to reduce errors resulting from noise and line pickup. This tuning should result in an attenuation of 20 db per octave either side of the center frequency. The input impedance of the detector should be approximately 500 kilohms and the sensitivity should be at least 20 microvolts.



MODEL 277 CAPACITANCE BRIDGE

SECTION II

OPERATING INSTRUCTIONS

2.1 CONTROLS AND TERMINALS

C RANGE Selector: The center dial selects from seven capacitance ranges and places the correct multiplier and units in the multiplier window.

CAPACITANCE Dials: The right-hand dials are used to balance the capacitive component of the bridge. The number displayed on these dials at balance times the multiplier indicated on the C RANGE Selector is the value of the capacitor under test.

DISSIPATION FACTOR Range Selector: The inner left-hand dial selects from three dissipation factor ranges and aligns the proper D multiplier.

DISSIPATION FACTOR Dial: The reading of the outer left-hand dial times the D multiplier and the generator frequency in kilocycles gives the dissipation factor of the capacitor under test.

AC GEN Terminals: The upper left-hand terminals are for attaching an external generator. An adjacent ground terminal is provided.

AC DET Terminals: The upper right-hand terminals are for attaching an external detector. An adjacent ground terminal is provided.

EXTEND D Terminals: The lower left-hand terminals are for attaching an external resistor in series with the D rheostat for special measurements. An adjacent ground terminal is provided.

UNKNOWN Terminals: The capacitance to be measured is connected to the lower center terminals. An adjacent ground terminal is provided.

EXTEND C Terminals: The lower right-hand terminals are for attaching an external resistor in series with the C DEKASTAT® (Decade Rheostat) for special measurements. An adjacent ground terminal is provided.

NOTE

When not using the EXTEND D or EXTEND C TERMINALS be sure their jumpers are securely in place.

2.2 WHAT THE BRIDGE MEASURES

The Model 277 bridge measures "direct" capacitance, with the unknown capacitor connected in an ungrounded arm of the bridge. Stray capacitance and leakage in parallel with the unknown capacitor are eliminated by grounded shielding. This permits the measurement of small three-terminal capacitors to better than 0.01pf without the use of a guard circuit or Wagner ground.

2.3 MEASURING CAPACITANCE

2.3.1 BASIC INSTRUCTIONS

1) Connect the capacitor to the UNKNOWN TERMINALS.

2) Set the D RANGE SELECTOR at .01 X.

3) Set the D DIAL at 0.

4) Set the C DIALS to read 3.000.

5) Adjust the C RANGE SELECTOR for a minimum indication on the null indicator.

6) Adjust the C DIALS and the D DIAL alternately for a null indication on the null detector.

7) Increase generator voltage and/or detector gain and repeat step 6.

8) If the C dial reading is less than 1.200, go to the next lower setting of the C range selector.

9) If the D dial reading is less than 10, go to the next lower setting of the D range selector.

The values of series capacitance C and dissipation factor D are as follows:

C = (C range selector setting) x (C dial reading)
D = (D range selector setting) x (D dial reading) x (f_{kc})

2.3.2 THREE-TERMINAL CAPACITORS

Three-terminal measurements make it possible to measure direct capacitance accurately by isolating the unknown capacitor from the effects of stray capacitances. For instance, in the typical capacitor shown in Figure 2.3.2a, there is stray capacitance and leakage resistance from each plate to the case. With two-terminal techniques, this causes an error in measurement. The bridge reading does not give the capacitance between the plates, but the total impedance of the entire network as seen from terminals 1 and 2.

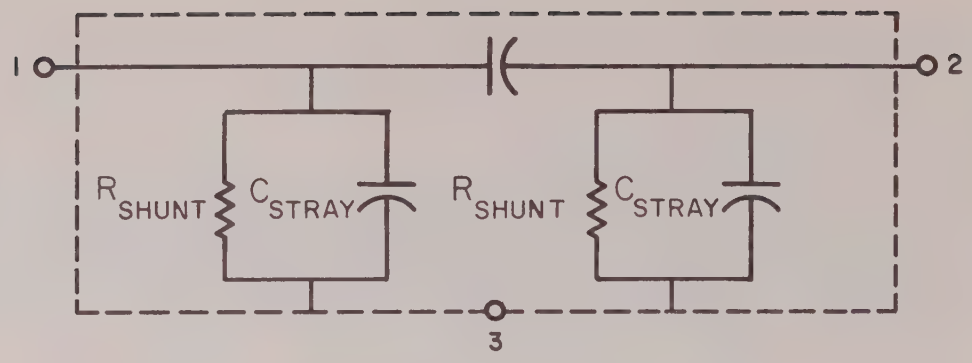


FIG. 2.3.2a

To isolate the direct capacitance, the capacitor case is used as a third terminal and is connected to the shield terminal of the bridge. If one of the stray capacitances is known to be greater, it should be connected from the center terminal to the shield terminal of the bridge. Thus this stray capacitance appears across the detector where it will cause no error. However, very large capacitance values may reduce the detector sensitivity.

The other stray capacitance is then across the standard capacitor arm of the bridge, in parallel with the standard capacitor, see Figure 2.3.2b. As the standard capacitor is 100,000pf, the stray capacitance will not cause significant errors unless it exceeds a few tens of pf.

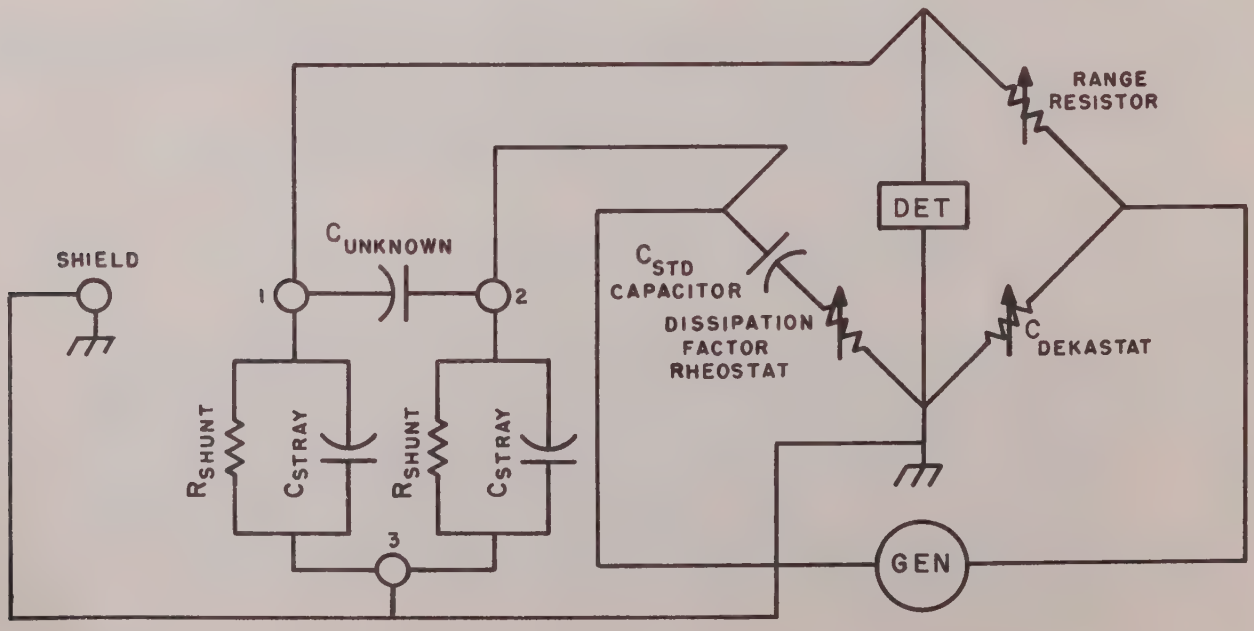


FIG. 2.3.2b

2.3.3 GROUNDED CAPACITANCE MEASUREMENTS

Because of inherent errors in making grounded capacitance measurements, the Model 277 Capacitance Bridge has been designed for ungrounded operation. For a grounded measurement several precautions and bridge changes are necessary. In making a grounded measurement the accuracy of the measurement may be reduced.

The generator and detector corners of the bridge must be interchanged. This is done by making the connections shown in the figures below:

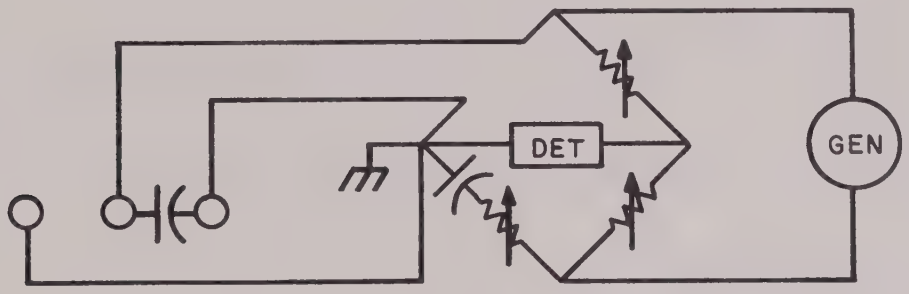


FIG. 2.3.3a

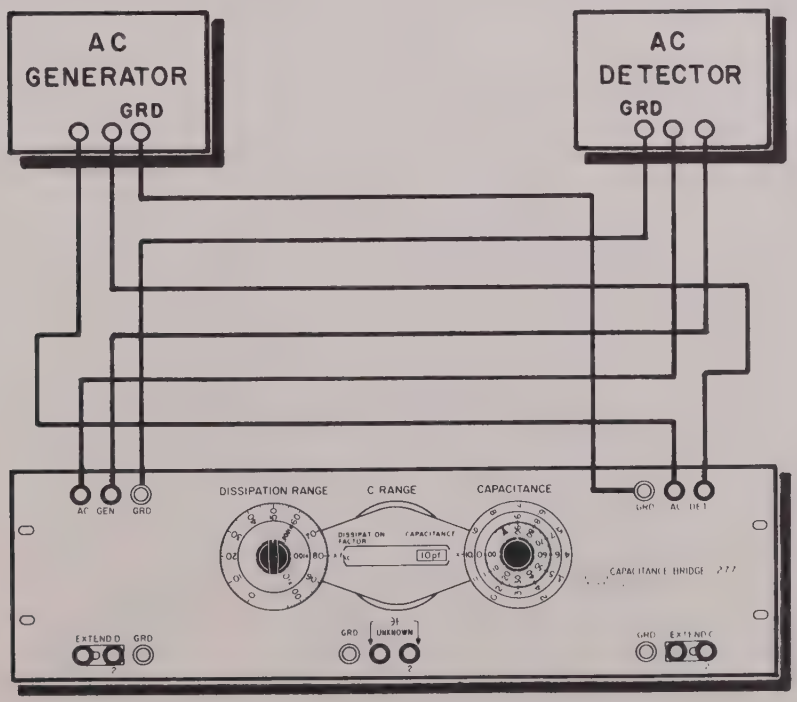


FIG. 2.3.3b

This connection throws nearly 100pf of internal capacitance across the unknown terminals of the bridge, so that a zero capacitance measurement is necessary. No appreciable correction will be needed for large capacitances, but for smaller capacitances this zero capacitance must be subtracted from the reading.

Procedure:

Make the necessary changes in the bridge circuit.

With nothing connected to the terminals, balance the bridge.

Record these values as C_0 and D_0.

Connect the ground side of the capacitor to the right-hand terminal of the bridge.

Connect the other terminal of the capacitor to the center terminal of the bridge.

Balance the bridge.

Record these values as C_m and D_m.

Compute the values of the unknown capacitor, C_x and D_x from the following equations:

For approximate values--

$$C_x = C_m - C_0$$

$$D_x = \frac{C_m D_m - C_0 D_0}{C_x}$$

For maximum accuracy--

$$D_x = \frac{C_m D_m (D_0^2 + 1) - C_0 D_0 (D_m^2 + 1)}{C_m (D_0^2 + 1) - C_0 (D_m^2 + 1)}$$

$$C_x = (D_x^2 + 1) \left[\frac{C_m}{D_m^2 + 1} - \frac{C_0}{D_0^2 + 1} \right]$$

Expected accuracy:

With grounded connections, the accuracy after calculation is approximately as follows:

±(1% + 1pf) for capacitance

±(.001 + 5% of reading) for dissipation factor

2.4 THINGS TO WATCH OUT FOR

2.4.1 LOW CAPACITANCE MEASUREMENTS

In making low capacitance measurements, there are two things to watch out for:

Be careful to avoid hum pickup.
Keep the stray capacitance at a minimum.

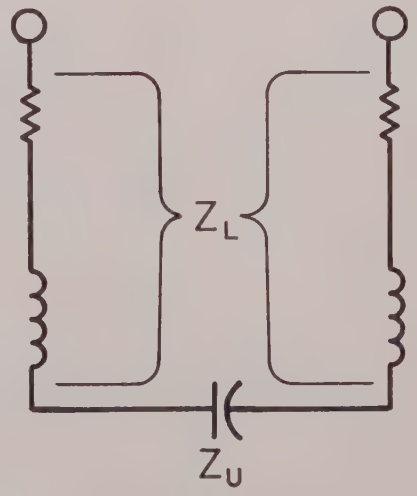
To minimize both effects, keep your hands as far as possible from the capacitor being measured.

Keep the leads as short and direct as possible. If extended leads are necessary, the lead from the center terminal should be shielded. See Section 2.9, "Extended Leads".

2.4.2 HIGH CAPACITANCE MEASUREMENTS

The bridge measures the total impedance connected to its terminals. Both the unknown capacitor and its leads contribute to this impedance. The leads have some resistance and inductance, which affect the value read from the bridge.

$Z_{MEASURED} = Z_U + Z_L$



Z_U = Impedance of unknown capacitor

Z_L = Impedance of leads

For the greatest accuracy, minimize the lead impedance. Short heavy leads will reduce the resistance. Closely-spaced twisted leads will reduce the inductance and the pickup of stray fields.

2.5 POLARIZING VOLTAGE

2.5.1 WHEN TO USE A POLARIZING VOLTAGE

Some capacitors need a polarizing voltage. For example, electrolytic and tantalytic units can be damaged by the reverse polarity half-cycle of the test frequency. Even if the capacitors are not damaged, erroneous readings may result.

2.5.2 WHEN A POLARIZING VOLTAGE IS NOT NECESSARY

A polarizing voltage is not always needed in these measurements. If the ac voltage is kept at a very low percent of the capacitors voltage rating, the capacitor will not be damaged, and the readings will be reasonably accurate.

2.5.3 HOW TO SUPPLY A POLARIZING VOLTAGE

The polarizing voltage is applied to the unknown capacitor as shown in Figure 2.5.3.

Keep the dc source well insulated, and keep the capacitance to ground as small as possible. Use of a battery is recommended.

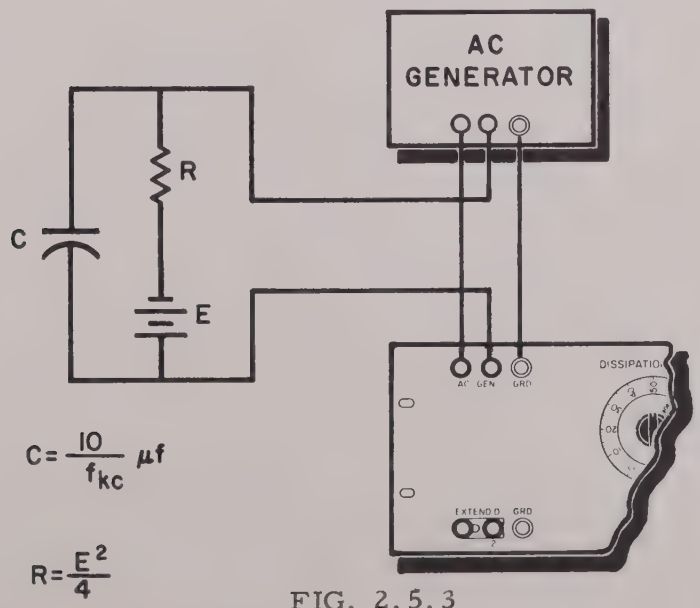


FIG. 2.5.3

The maximum recommended polarizing voltage is 300V.

The polarizing voltage should be in series with the ac generator. Direct current is then blocked from flowing through the bridge by the unknown capacitor in one arm, and the standard capacitor in the other arm.

The dc source should be by-passed by a capacitor. A current limiting resistor will protect the bridge from damage in case of short circuits.

2.6 VOLTAGE MEASUREMENT

To measure the ac voltage applied across the unknown capacitor:

Connect the ground terminal of a high impedance ac voltmeter to a ground terminal of the bridge.

Connect the input terminal of the voltmeter to the right-hand unknown terminal of the bridge.

Balance the bridge.

Read the voltmeter. With the bridge balanced, this voltage is equal to the ac voltage across the unknown capacitor, but the capacitor has not been loaded by the voltmeter.

2.7 EQUIVALENT SERIES RESISTANCE AND DISSIPATION FACTOR

The bridge measures effective series capacitance and dissipation factor. From these values, storage factor and equivalent series resistance can be calculated.

$$Q = \frac{1}{D}$$

$$R_s = \frac{D}{2\pi f C_s}$$

Q - Storage factor

R_s - Equivalent series resistance, in kilohms

D - Measured dissipation factor

C_s - Measured equivalent series capacitance, in μf

f - Frequency, in kilocycles

2.8 EQUIVALENT PARALLEL CIRCUIT

From the equivalent series capacitance and dissipation factor measured, the equivalent parallel circuit can be derived.

$$Q = \frac{1}{D}$$

$$C_p = \frac{C_s}{1 + D^2}$$

$$R_p = \frac{1 + D^2}{D^2} \quad R_s = \frac{1 + D^2}{D} \quad \frac{1}{2\pi f C_s}$$

Q - Storage factor

C_p - Equivalent parallel capacitance, in μf

R_p - Equivalent parallel resistance, in kilohms

D - Measured dissipation factor

C_s - Measured equivalent series capacitance, in μf

R_s - Equivalent series resistance, in kilohms

f - Frequency, in kilocycles

The D of the equivalent parallel circuit always equals the D of the equivalent series circuit. The same is true of Q.

2.9 EXTENDED LEADS

Sometimes it is necessary to use extended leads. This can be done easily, without causing error in the measurement.

Connect a shielded lead to terminal UNKNOWN 1.

Connect the shield of this lead to the adjacent shield terminal of the bridge.

Connect an ordinary clip lead to terminal UNKNOWN 2.

The capacitance between the shield and the center conductor is now across the detector. This keeps it from causing any error. If this stray capacitance is greater than 500pf, it may reduce the detector sensitivity.

The stray capacitance from the unshielded lead to ground is across the standard capacitance arm of the bridge. As the standard capacitor is 100,000pf, the stray capacitance will not cause significant errors unless it exceeds a few tens of pf.

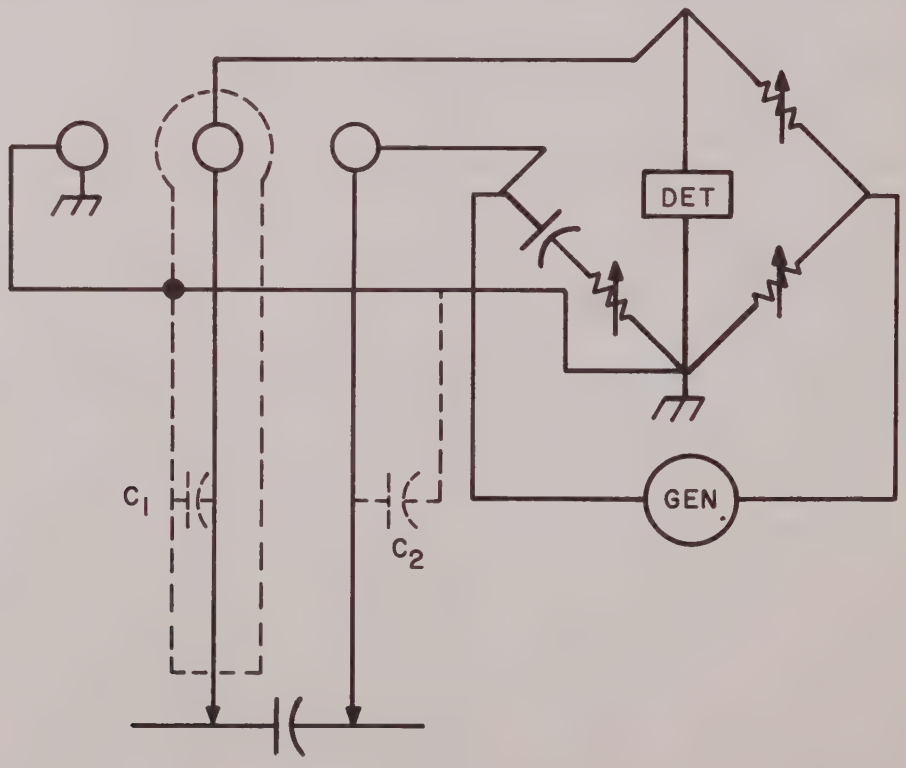


FIG. 2.9

C_1 - Capacitance from center conductor to ground
C_2 - Capacitance from unshielded conductor to ground

SECTION III

MAINTENANCE

3.1 CLEANING AND LUBRICATING SLIDE-WIRE RHEOSTAT

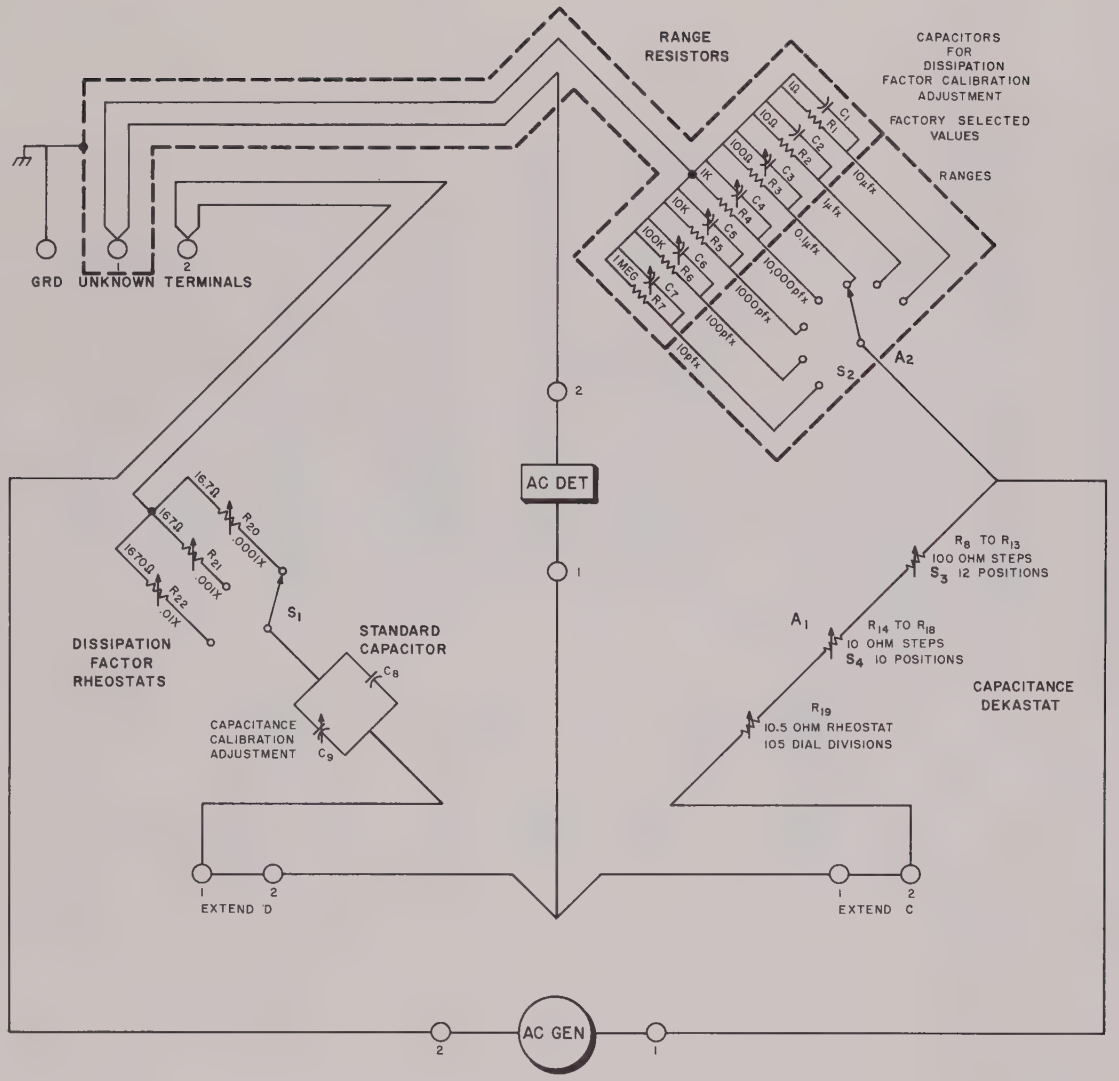
Remove rear bridge cover.

Remove DEKASTAT dust cover. Follow instructions on dust cover.

Using a small strip of crocus cloth, wipe both slide wires. Make two or three continuous rotations. Care should be taken to rotate the slider out of the way to avoid changing its contact force. To complete cleaning, wipe slide-wires and contacts with a clean, dry, lint-free cloth to remove loose particles. Apply a liberal amount of RPM Aviation Grease #5 to the contact surface of the wire.

3.2 ADJUSTING SLIDE-WIRE RHEOSTAT

It is recommended that instrument be returned to factory if slide-wire contacts require adjustment. Where it is absolutely necessary to make repairs yourself, adjust each slider so that contact force measures 75 to 100 grams. USE EXTREME CAUTION to avoid damaging slide-wires.



4.1 MODEL 277 CIRCUIT DIAGRAM

4.2 PARTS LIST

The following parts list is in alpha-numerical order of the circuit reference designator. Miscellaneous parts are included at the end of the list. Manufacturer of the part is given in a code number according to the Federal Supply Code for Manufacturers; see list of manufacturers below. Parts recommended as spares to sustain operation in isolated locations are indicated in the recommended spare parts column.

Parts manufactured by Electro Scientific Industries must be ordered from the factory. When ordering parts from the factory include the following information:

Model and serial number of the instrument
Electro Scientific Industries part number
Circuit reference designator
Description of part

CODE LIST OF MANUFACTURERS

11837	ELECTRO SCIENTIFIC INDUSTRIES Portland, Oregon
56289	SPRAGUE ELECTRIC CO. North Adams, Massachusetts
65092	WESTON INSTRUMENTS DIVISION OF DAYSTROM, INC. Newark, New Jersey
71279	CAMBRIDGE THERMIONIC CORP., Cambridge, Massachusetts
80583	HAMMARLUND CO., INC. New York, New York
84171	ARCO ELECTRONICS INC. Great Neck, New York

Ckt Ref	Description	Mfr	ESI Part No.	Qty Used	Recm SP
A_1	Ass'y, Capacitance DEKASTAT	11837	2845	1	
A_2	Ass'y, Range Multiplier	11837	2735	1	
C_1	Capacitor, Fxd, approx 0.47μf, Selected Value	56289		1	
C_2	Capacitor, Fxd, approx 0.012μf, Selected Value	56289		1	
C_3	Capacitor, Trimmer Mfr PN 469	84171	1938	1	
C_4	Capacitor, Trimmer Mfr PN 463	84171	1937	1	
C_5	Capacitor, Trimmer Mfr PN 460	84171	1936	1	
C_6, C_7	Capacitor, Trimmer Mfr PN CST 6	71279	1427	2	
C_8	Capacitor, Std, 0.1μf	11837	4092	1	
C_9	Capacitor, Variable, Air, 6.3-140pf, Mfr PN APC-140-C	80583	5277	1	
R_1	Resistor, Fxd, Precision, 1Ω, Part of Ass'y A_2	11837	2824	1	
R_2	Resistor, Fxd, Precision, 10Ω, Part of Ass'y A_2	11837	2823	1	
R_3	Resistor, Fxd, Precision, 100Ω, Part of Ass'y A_2	11837	2767	1	
R_4	Resistor, Fxd, Precision, 1KΩ, Part of Ass'y A_2	11837	2822	1	

Ckt Ref	Description	Mfr	ESI Part No.	Qty Used	Recm SP
R_5	Resistor, Fxd, Precision, 10KΩ, Part of Ass'y A_2	11837	2821	1	
R_6	Resistor, Fxd, Precision, 100KΩ, Part of Ass'y A_2	11837	2820	1	
R_7	Resistor, Fxd, Metal Film, 1 Meg, Mfr PN 9852, Part of Ass'y A_2	65092	2001	1	
R_8	Resistor, Fxd, Precision, 100Ω, Part of Ass'y A_1	11837	2826	1	
R_9 - R_{13}	Resistor, Fxd, Precision, 200Ω, Part of Ass'y A_1	11837	2825	5	
R_{14}	Resistor, Fxd, Precision, 10Ω, Part of Ass'y A_1	11837	2828	1	
R_{15}-R_{18}	Resistor, Fxd, Precision, 20Ω, Part of Ass'y A_1	11837	2827	4	
R_{19}	Resistor, Variable, 10.5Ω, Part of Ass'y A_1	11837	2771	1	
$R_{20, 21, 22}$	Resistor, Variable, D Rheostat	11837	2721	1	
S_1	Switch, Rotary, D Range Selector	11837	1220	1	
S_2	Switch, Rotary, Range Selector	11837	2725	1	
$S_{3, 4}$	Switch, Rotary, Capacitance Dekastat	11837	5633	2	

Ckt Ref	Description	Mfr	ESI Part No.	Qty Used	Recm SP
	MISCELLANEOUS				
	Swing Lug	11837	3247	2	1
	Washer, Shoulder	11837	1277	4	
	Washer, Shoulder	11837	8823	6	
	Binding Post	11837	1393	15	6
	Cap, Binding Post, Metal	11837	1172	5	2
	Cap, Binding Post, Ins	11837	1170	10	
	Dial, C Rheostat	11837	2707	1	
	Dial, D Range Selector	11837	2706	1	
	Dial, C Decade, Center	11837	5151	1	
	Dial, C Decade, Outer	11837	4275	1	
	Dial, Range	11837	2782	1	
	Dial, Dissipation Factor	11837	2780	1	

CLAIM FOR DAMAGE IN SHIPMENT

This instrument should be tested upon receipt. If it fails to operate properly, or is damaged in any way, a claim should be filed with the carrier. A full report of the damage should be forwarded to us by the claim agent. We will then advise you of the disposition to be made and arrange for repair or replacement. Include model and serial number when referring to this instrument.

WARRANTY

Electro Scientific Industries, Inc. warrants each instrument and component parts to be free from defects in material and workmanship. Electro Scientific Industries, Inc. will service any instrument and replace parts thereof (except tubes, fuses and batteries) which shall, within one year after making delivery to the original purchaser, prove to be unsatisfactory.

If the fault has been caused by misuse or abnormal conditions or operation, a nominal charge will be made for repairs. In this case, an estimate will be submitted before making such repairs.

Electro Scientific Industries, Inc. reserves the right to make changes in design at any time without incurring obligation to modify units previously purchased.

Electro Scientific Industries

7524 S. W. Macadam Avenue • Portland 19, Oregon

ESI instruments are carefully engineered and made to the most exacting standards of workmanship and accuracy in a modern and well-equipped factory.

Field Engineers are maintained in principal cities as a service to our customers. Customers are invited to contact our nearest field engineer or to consult our engineering staff for further information regarding ESI instruments and their applications.

MP MASTER
MA30731